

A GIS Suitability Analysis of The Potential for Rooftop Agriculture in New York City



Danielle Berger

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Danielle Berger
Graduate School of Architecture, Planning and Preservation
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Advisor: Professor Elliott Sclar
Reader: Kubi Ackerman

Cover photo credit: Brooklyn Grange Farm

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Abstract

Urban agriculture and the capacity to grow food in urban landscapes has become a significant aspect of sustainable development especially in New York City. Urban agriculture is part of the larger idea of green infrastructure, which has environmental benefits ranging from reducing storm-water runoff, mitigating the urban heat island effect, reducing the need for energy intensive cooling systems in the summer months and increasing biodiversity. Urban agricultural projects have gained traction in progressive cities across North America like San Francisco, CA, Portland, OR and Vancouver, BC, Canada. New York City presents many challenges to urban agriculture, primarily the lack of open space for commercial urban farms due to the dense built landscape. In response to this issue, New York City has looked to rooftops for urban agriculture solutions. A handful of rooftop farms already exist in the city, most notable Brooklyn Grange and Gotham Greens, which are two of the most successful urban farms in the world. This study looks at the potential for rooftop urban agriculture in New York City through a GIS analysis. The model utilizes publicly available datasets to identify the buildings with the greatest potential for rooftop farms, greenhouses, or intensive green roofs. The model subsequently also identifies roofs with the structural potential for extensive non-agricultural green roofs. The model focuses on the North Brooklyn Industrial Business Zone on the south side of Newtown Creek and has identified over 50 acres of suitable roof space for agricultural projects. The results of this model will hopefully spur investment and increase awareness about the potential for urban agriculture and green roofing infrastructure among the public, policy makers, advocacy groups, and investors.

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I. Introduction

“I think people need to realize that we are in a deep crisis in this country, not only economic but ecological, cultural and social. And food, there is a food crisis here in terms of the quality and availability of food.”

Miguel Altieri, UC Berkeley, Edible City, 2011.

Urban agriculture has recently garnered a significant amount of attention from local food activists to municipal governing bodies for its multitude of benefits to urban systems. Agriculture within urban landscapes has existed in varying forms for centuries as a necessary method of food production. Urban agriculture is most simply defined as the act of food production, processing and or distribution within a city (Bailkey, 2000). This can take the form of community gardens, rooftop greenhouses, apiaries, animal husbandry or green roofs with food growing capacity.

Food has been historically grown in close proximity to areas of consumption because there was no option for long-range transportation. This idea seems so inherent to a society's success yet has been all but forgotten in today's modern urban landscapes. It was not until the advent of commercial farming, refrigerated transportation and suburban sprawl did urban agriculture become something of a novel idea and an activity far removed from cities both spatially and consciously. As the modern city, particularly in the U.S., took horizontal rather than vertical growth forms, the notion of food production in urban areas seemed like an unprofitable land use and was quickly pushed out of the cognizance of planners and policymakers in favor of real estate development projects.

Urban food production has experienced a resurgence in our collective urban consciousness in response to a variety of social and environmental realities. Issues such as climate change, obesity, the overuse of petrochemical fertilizers, storm water and sewage overflow and the urban heat island effect are all urban systems, or parts thereof, that serve to benefit from urban agriculture initiatives. Urban agriculture is now seen as an integral part of sustainable development in the effort to reduce the negative effects of urbanization. New York City provides a unique urban environment in which to study the potential for urban agriculture and in particular rooftop agriculture. This

paper seeks to examine the suitability for rooftop agriculture as a subcategory of green roof infrastructure in New York City utilizing geospatial analysis. It should be noted however, that New York City does not have the growing capability to fully sustain its population but through urban agricultural initiatives, there is a potential to contribute to the current food system while mitigating some of the environmentally detrimental effects of urban development.

Geography, Climate & Statistics

New York City is unlike any other city for numerous reasons yet here we will focus on geography and demographics. Comprised of five boroughs, which are also New York state counties, the city encompasses 305 square miles and has a population of roughly 8 million. 1 in 36 Americans call New York City home making New York the most densely populated city in the country (Dept. of City Planning, 2012). This naturally correlates to high land values, an extremely dense built environment and a massive market for food distribution and consumption. Not to be ignored however, is the agricultural hardness of the area. The U.S. Dept. of Agriculture has divided the country in hardness zones, which are based on average minimum temperature, precipitation, climate and soil. Although current soil conditions do not factor into this study, it is an integral part of hardness evaluations. New York falls into zones 7a and 7b which make it agriculturally viable to grow a variety crops (USDA, 2012). Agricultural zones do not pertain to greenhouse crops therefore New York City could have a much higher capacity for growing crops than what is defined by the USDA. Thus there is incredible potential for New York City to spearhead the rooftop agricultural initiatives due to built landscape and position on the global stage as a megacity (Lewis, 2007).

II. Case Studies & Background Information

Urban agriculture has gained popularity in cities around the world in the last 20 years. From Moscow to Havana, urban agriculture has flourished as a sustainable practice with pragmatic benefits. International cities have successfully integrated food production into the urban fabric in order to address the basal need for a local food supply. In North America, it has been more challenging to amalgamate farming with urbanization, which has largely been a function of politics. However in San Francisco, Portland, and Vancouver, BC, there has been significant progress towards the integration of urban agriculture into planning, public awareness and policy making. Although New York City is somewhat behind the progressive cities on the west coast, lessons can be learned and adapted for the unique conditions of New York. This section will showcase the success other municipal urban agriculture initiatives and GIS models if applicable and briefly touch on the other urban systems that stand to benefit from urban agriculture. Rooftop urban agriculture is a niche form urban farming that has yet to gain popularity on a large scale. At-grade and above-grade urban agriculture are two different systems in terms of engineering and feasibility and much more literature is available on at-grade projects and developments.

San Francisco, California

San Francisco has had a long history of social activism, sustainability and having an environmentally conscious constituency. This has coalesced into the Bay Area having some of the most progressive urban agriculture legislation in the country (Falk, 2011). In 2008, the city ranked 2nd overall in the SustainLane sustainability rankings (Karlenzig, 2007). This study ranked U.S. cities based on local agriculture infrastructure, land use planning and sustainability management among several other factors. Urban farming in San Francisco began as disaggregated, non-profit, grassroots movements that sought to forge a sense of community through farming as well as contribute to the local food supply and has recently been integrated municipal involvement and action (Goldstein, 2011). Much to the delight of urban farmers across the Bay Area, former Mayor Gavin Newsom put words into action. In 2010, the former Mayor urged for “all city

departments to carry out implementing actions consistent with the goal of fostering local food production in the City.” (San Francisco Planning Department, 2010). As a result, San Francisco has worked to explicitly integrate agriculture in the zoning code. The new urban agriculture zoning ordinance has divided agricultural activities into three categories, each of which have different setback, equipment and aesthetics regulations. This allows for varying levels of urban farming to take place within the city limits ranging from neighborhood farms to large-scale agriculture businesses (Goldstein, 2011). The ordinance change also pushes for the aggregation of city agricultural datasets, coordination of state and federal funding and the development of a strategic plan for the future of San Francisco urban farming. This monumental leap towards sustainable development on the municipal level has motivated many other cities to re-examine their own city zoning ordinances.

The San Francisco ordinance contains policies similar to those recommended for New York City by the Design Trust for Public Space’s report, *Five Borough Farm* released in 2012. The report urges New York City to adopt an urban agriculture policy and plan that establishes goals, objectives, a citywide land use scheme for garden and farm development, and adequate agency budgets to support existing and future urban agriculture activity (Cohen, 2012). New York has the ability to integrate many of the successful urban agriculture policies and zoning ordinances created by the city of San Francisco.

Portland, Oregon

Further up the Pacific Coast lies the sustainability capital of the country, Portland, OR. Ranked as the number one city in the U.S. for sustainability in 2008 by SustainLane. This mid-sized city is packing a punch in terms of sustainable development and urban agriculture projects (Karlenzig, 2007). Popular Science also dubbed Portland the “greenest city in America” the same year (Svoboda, 2008). This reputation of excellence in sustainability is well deserved and cities around the country can learn from Portland’s successes. Residents of Portland are passionate about the environment and have been active in the localization of their food

systems since the mid-1970s (Goldstein, 2011). In 1975, Portland's Dept. of Parks and Recreation adopted the Community Garden program, which allowed residents to rent plots and receive the necessary water, fencing and support to start their own gardens. The program has been wildly successful and in 2005 there was a 3-year waiting list to receive a plot of land (Hess, 2005). This highlights the demand for locally grown produce within the city limits and a desire from residents to become active producers in the food system. The city also implemented an urban growth boundary in 1979, a common planning tool, which was intended to reduce urban sprawl develop while preserving rural and agricultural lands (Staley, 1999). This has resulted in high land values within the boundary and a struggle between developers and urban farmers. In response to the demand for land for urban agriculture projects, the city commissioned Portland State University to create a land inventory of city owned lots and assess site suitability for urban agriculture. This 2005 land inventory was one of the first GIS models implemented for urban agriculture suitability analysis (Mendes, 2008). The project also integrated community member suggestions and concerns regarding urban agriculture projects as well as local land use and zoning regulations. The results of this analysis were presented to the Portland City Council as "The Diggable City Project" and started a dialog among policy makers and constituents regarding the potential to localize the food system. Since the report, there has been significant progress in integrating urban agriculture into Portland's zoning regulations and strategic planning goals with the input of advocacy organizations like the Portland/Multnomah Food Policy Council, Bureau of Planning and Office of Sustainable Development (Mendes, 2008). Portland has been updating its zoning codes to establish regulations for urban food production and distribution activities that support access to healthy food. On April 24, 2012, the zoning amendments were unanimously approved.

Vancouver, British Columbia

Vancouver has been recognized internationally for its progressive urban governance and sustainability based planning. Canada's densest city has been a leader in both at-grade and above-grade urban agriculture initiatives. Similar to Portland and San Francisco, the

Pacific coast residents of Vancouver are an environmentally conscious population who are concerned with sustainable development and the reducing negative environmental impacts of urban landscapes. In 2003, after years of community advocacy, the City Council approved a Food Action Plan for creating a just and sustainable food system (Mendes, 2008). Two years later, in 2005, on the heels of the Portland land inventory, Vancouver decided to replicate the study on their city. The city enlisted graduate students to perform the GIS analysis. Unlike Portland, Vancouver has an extremely dense built environment, which resulted in the GIS model identifying few vacant parcels for urban farming. Additionally, the comparatively low revenues that urban agriculture produces cannot compete with the rents from other forms of development. This is a similar issue in New York City. However, despite the lack of vacant land for urban agriculture, city council recognized the importance of localized food production and the need for it to be integrated into long term planning (Mendes, 2008). As a result of the dearth of vacant land, urban farming in Vancouver must look to above-grade solutions for sustainable development initiatives. In September 2012, construction began on the city's largest greenhouse, a 6,000 square foot space atop a 5-story city owned building. The greenhouse will utilize the proprietary technology of Vancouver-based Alterrus Systems Inc. and VeriCorp. urban farming systems. The system is expected to produce 150,000 – 200,000 lbs of leafy greens per year, which will go directly into the local food system (Salo, 2013).



Image 1: VeriCorp greenhouse

III. Other Affected Systems

The food system is naturally the primary urban system that stands to benefit from localized food production. However there are several other systems that can be positively affected by urban agriculture projects. There is a significant amount of literature pertaining to the following systems and how they stand to benefit from urban farming but for the purposes of this project, only the main topics will be discussed. The ancillary urban systems that will be highlighted are public health, energy and water systems.

Public Health

Public health in terms of nutrition, personal wellness and community betterment, has the potential to be greatly improved through urban agriculture initiatives. The consequences of hunger and malnutrition are obvious and urban agriculture has the ability to increase food security in current food deserts with nutritious and accessible food (Brown, 2000). The extent to which urban agriculture can impact hunger necessarily depends on the amount of food grown. Although urban farms would likely only contribute a small portion to the total urban food supply, if distributed properly that amount could have significant public health benefits. This could entail identifying food desert communities and concentrating agricultural efforts in those areas. Also, by leveraging existing food infrastructure such as greenmarkets and neighborhood bodegas, locally grown food could be easily accessed by consumers. Improved personal nutrition inherently improves every other aspect of a person's life from work performance, happiness, stress levels and all around wellness, which gives urban agriculture a social plat

form to stand upon (Brown, 2000). It has also been shown that community gardens curb neighborhood violence and crime (Malakoff, 1994). Planners and policymakers should acknowledge urban agriculture as a tool that can be utilized to build healthier, safer neighborhoods.

Environment: Energy and Water

Urban agriculture is part of the larger sustainable development category of green roofing. Green roofs are roofs with a vegetative surface and substrate, which provide a variety of eco-system "services" in urban areas (Oberndorfer, 2007). Green roofs essentially replace the green space lost with building construction and have the capacity for food production under the appropriate circumstances while benefiting the water and energy systems of the city as well as increasing biodiversity in urban landscapes.

Greenroofing shows promise for contributing to local habitat conservation and diversification. Green roofs are commonly inhabited by various insects, including beetles, ants, flies, bees, and spiders (Oberndorfer, 2007). Rare and uncommon species of beetles and spiders have also been recorded on green roofs particularly in Switzerland and the United Kingdom. In light of this, green-roofing designs are seen as a strategy for increasing urban biodiversity.

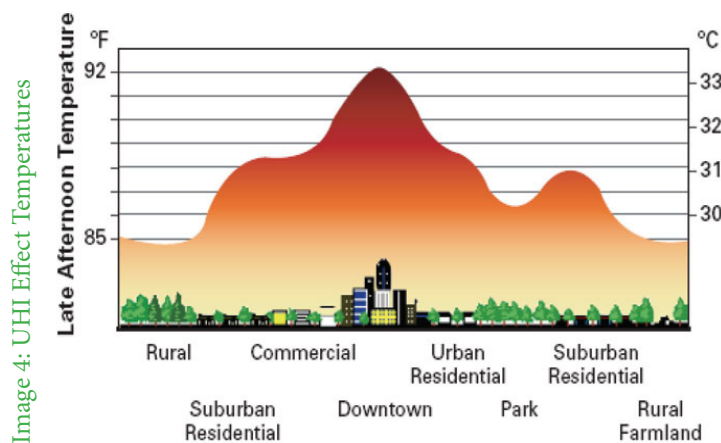
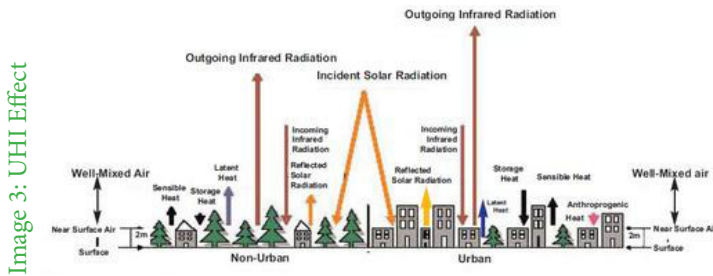
Roofs that are vegetated with crops or other flora can reduce the ambient temperature, air pollution and aid in the mitigation of the urban heat island effect. Urban heat islands are the result of urban infrastructure such as roofs, roads, buildings and other low albedo surfaces absorbing rather than reflecting incoming solar radiation leading to increased temperatures relative to non-urban areas (Urban Design Lab, 2011). As a result, NYC is on average 2-4°C warmer on any given day than the surrounding areas. The process of green roofing increases the albedo of the surface while also insulating the structure below thus reducing the need for air conditioning and other cooling systems use during peak demand in the summer months. With global temperatures forecasted to increase, it is necessary for urban areas to implement sustainable development practices that will reduce the negative effects of a



Image 2: NYC Green Carts

warming planet. Therefore, roofs that are put into agricultural production stand to increase food security while cooling both the natural and built environment.

The following images visualize the urban heat island effect.



Green roofs also have the ability to mitigate the city's storm-water runoff and combined sewer overflow problem. Similar to global temperature, precipitation is forecasted to increase in the NYC area, making the management of storm-water crucial. Runoff from urban areas carries soluble pollutants to lakes, rivers and streams causing eutrophication and contamination (EPA, 2012). Additionally, storm-water runoff in New York City overloads the city's combined sewer system, which handles both sewage and storm-water, leading to hazardous overflows into the Hudson and East Rivers. Green infrastructure has been identified as a sustainable practice that could effectively reduce complications with urban storm-water by creating pervious vegetated surfaces, which absorb precipitation.

Green roofs mitigate stormwater runoff in two primary ways, which reduces the number of combined sewer overflow (CSO) events. Precipitation is absorbed by the soil media and is released when saturation has been reached thus delaying the time between the rain-

fall event and when the stormwater is released into the sewer system. The second way stormwater flow is reduced is through evapotranspiration. This is the process by which storm-water is absorbed by the vegetation and soil and released directly into the atmosphere. Retained water never enters the sewer system (Urban Design Lab, 2011). It is suggested that agriculture green roofs may have a greater potential to reduce storm-water runoff due to their deeper soil depths however soil irrigation and baseline saturation levels must be taken into consideration. Study is currently being done at Columbia University to quantify the amount of storm-water which is delayed or diverted from the NYC sewer system post-rainfall events.

Green roofs, whether in the form of regular landscaping or crop production have an incredible ability to benefit the microclimate, energy, and water components of urban systems. By cooling the ambient air, reducing electricity use in the summer months, filtering rain water and limiting sewage overflows, green roofs are sustainability multi-taskers and need to be integrated into design and building regulations on the municipal level.

IV. The New York City Context

New York City is unlike any city in the U.S. for a multitude of reasons. The culture, the food, the buildings and the people are all components of what makes New York a wonderfully diverse urban landscape. However, the city also boasts the highest land values in the country, a very high population density, extreme disparities in income and fresh food availability (two factors which coincide, not incidentally), extreme temperatures and the greatest levels of storm-water runoff and combined sewage overflow (CSO) in the country. As a result, it has been difficult to promote and actualize urban agriculture in New York City as a sustainable development practice. There has been a significant amount of research on the practicality, feasibility and benefits of urban agriculture however implementing such projects in New York City has been challenging.

It is difficult to make it economically viable for a vacant parcel in New York City to be used for urban farming. The price of land is too high and the returns of farming are often too low to be considered a profitable business option. In addition, most vacant land in NYC is assumed to be contaminated to some degree, until proven otherwise, and thus not suitable to grow crops for human consumption. This leads to the need for land remediation (Urban Design Lab, 2011). Rooftop urban agriculture is a profitable, alternative approach to ground level urban agriculture in NYC that utilizes under- or unused space. Other than for photovoltaic installations, there is little competition for the use of rooftop space.

Brooklyn Grange is currently the largest rooftop farm in the world and has become of model of success for urban agriculture projects. One of

the goals of this thesis is to identify other roofs in NYC that could be put into food production in a similar fashion to Brooklyn Grange. Urban agriculture has become somewhat trendy in today's food-conscious culture but this project seeks to analyze the possibilities in New York City rooted in spatial data and GIS modeling.

The following map shows current rooftop farm projects, including rooftop greenhouses, and relative sizes in the city.

Image 5: Fisheye view of Manhattan



V. Research Design

This study seeks to understand how the potential for rooftop agriculture and to a greater extent green roof infrastructure in New York City can be determined using a geographic information system (GIS). A GIS, is an electronic information system that analyzes, integrates, and displays information based on its location. GIS systems have powerful visual display capabilities that present the results of an analysis on maps at a wide variety of scales. GIS is an excellent technology to understand and solve problems associated with data whose common attributes are related to place and geography. A GIS approach to this question allows for the integration of spatial information into the analysis, such as distance from a school or location within a designated boundary. Using geospatial data also allows for analysis to be performed on data attributes not otherwise available, i.e. building footprint area. The model will be created using ESRI ArcGIS 10.0 software and public datasets created by various entities including the NYC Dept. of City Planning, NYC Economic Development Corporation and CUNY. The results of the model will be able to be leveraged by building owners, planners, policy makers, advocacy groups, entrepreneurs and the public to increase awareness about the potential for rooftop agriculture. By creating a GIS model, the analysis could be replicated in other cities given the appropriate datasets are available.

VI. Methodology- Phase 1

The primary dataset used for this analysis was the 2009 NYC Dept. of City Planning PLUTO building footprint shapefile for all five boroughs. Versions of this dataset are available via the Dept. of City Planning and current through 2012, however 2009 was the only accessible version of the data through Columbia University. The following is the abstract from the DCP's website describing the dataset.

“This dataset represents a compilation of data from various government agencies throughout the City of New York. The underlying geography is derived from the Tax Lot Polygon feature class which is part of the Department of Finance’s Digital Tax Map (DTM). The tax lots have been clipped to the shoreline, as defined by NYCMAP planimetric features. The attribute information is from the Department of City Planning’s PLUTO data. The attribute data pertains to tax lot and building characteristics and geographic, political and administrative information for each tax lot in New York City. The Tax Lot Polygon feature class and PLUTO are derived from different sources. As a result, some PLUTO records did not have a corresponding tax lot in the Tax Lot polygon feature class at the time of release. These records are included in a separate non-geographic PLUTO Only DBase (.dbf) table. There are a number of reasons why there can be a tax lot in PLUTO that does not match the DTM; the most common reason is that the various source files are maintained by different departments and divisions with varying update cycles and criteria for adding and removing records. The attribute definitions for the PLUTO Only table are the same as those for MapPLUTO. DCP Mapping Lots includes some features that are not on the tax maps. They have been added by DCP for cartographic purposes. They include street center ‘malls’, traffic islands and some built streets through parks. These features have very few associated attributes.” (Dept. of City Planning, 2012).*

The first selection in the analysis was to isolate buildings that fall within a commercial or manufacturing zoned area. This allows for the operation of commercial-scale as opposed to community gardens. For-profit farms should be located within these city-sanctioned zones due to their commercial activities (Urban Design Lab, 2011). Residential use buildings were removed from the dataset. Such buildings are identified as the following in the land use attribute field:

- ‘01’ - one & two family buildings
- ‘02’ - multi - family walk- up buildings
- ‘03’ - multi - family elevator buildings

The next selection criteria identified buildings that were 10 floors or less. Rooftop conditions above 10 floors are assumed as being less hospitable to plants and there are logistical concerns with the movement of supplies, people, and produce (Urban Design Lab, 2011). There are successful rooftop farms above 10 floors, such as the Fairmont Royal York Roof Garden in Toronto, ON (18 floors) but for the purpose of this model, 10 floors is the maximum building height that will be used.

Roof square footage was then integrated into the model. Buildings that had a footprint of larger than 10,000 square feet were selected (Urban Design Lab, 2011). This model is making the approximate assumption that the roof area of a building is the same area as the building footprint. The building footprint area is automatically calculated as shape geometry in ArcGIS. Commercial and manufacturing buildings usually have vertical facades with minimal setbacks (NYC, Department of City Planning, 2013). This size calculation does not take into account any rooftop obstructions or protrusions such as air conditioning units. Although there are no definitive size requirements for a commercial urban roof farm to be profitable, it is widely accepted the larger the farm, the more profitable.

Buildings classified as having noxious or utility uses were identified and removed from the dataset as they are unlikely to have potential for urban agriculture. Building class is a field in the building dataset. Noxious or utility use building classes and descriptions as follows (Urban Design Lab, 2011) (NYC DCP) :

- 'F1' - heavy manufacturing
- 'G3' - garage and gas station combined
- 'G4' - gas station with enclosed lubrication plant or workshop
- 'G5' - gas station without enclosed lubrication plant or workshop
- 'U1' - bridges, tunnels, highways
- 'U2' - electric utilities, gas
- 'U4' - telephone utilities
- 'U5' - communications facilities (other than telephone)
- 'U8' - revocable consents

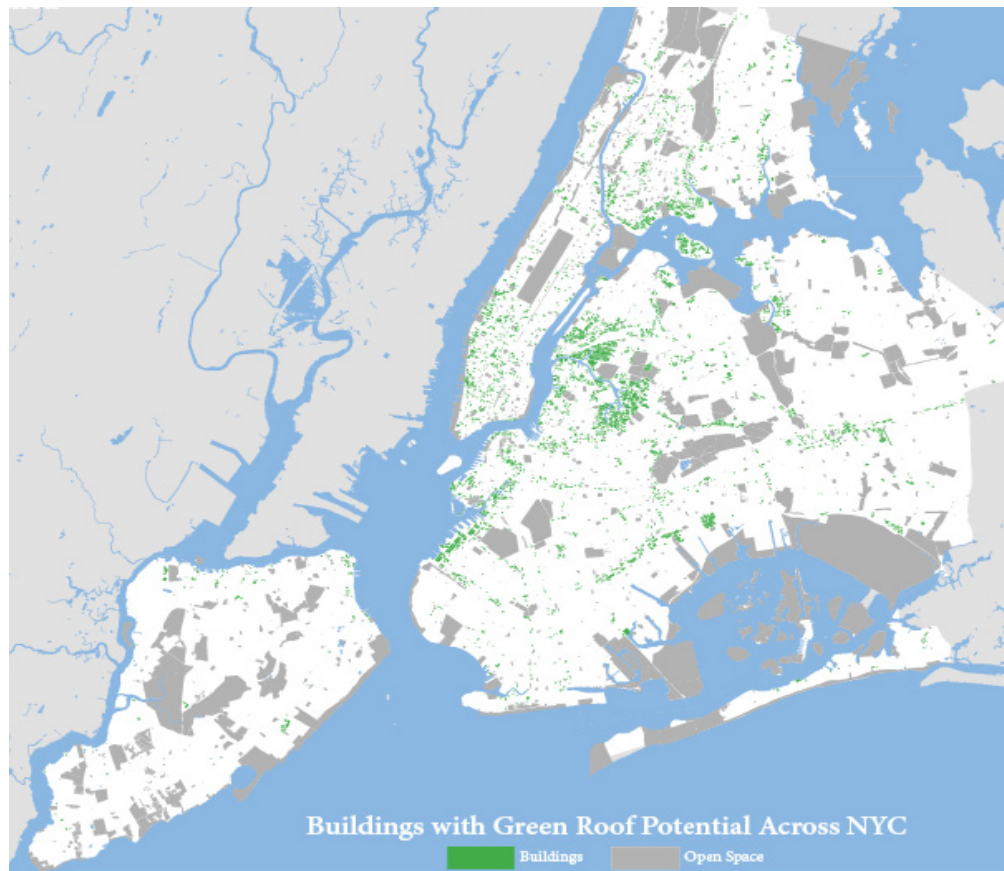
Building construction year was the final criteria integrated into this phase of the model. The construction year of a building roughly correlates to live roof load capacity. The live roof load is the amount of weight expressed in pounds per square foot (psf) that the roof can support and is critical in establishing what type of green infrastructure can be installed, i.e. intensive, extensive or greenhouse.

Buildings constructed in New York City prior to 1968 were built in accordance to the 1938 or 1916 building codes depending on year of construction. The 1916 Building Code states in Article 3, § 53.6 that a roof with a pitch of 20 degrees or less must have a minimum live load of 40 psf (City of New York, 1916). The same live load requirements appear in Article 8, Sub-Article 3, § C26-347.0 of the 1938 Building Code (Department of Buildings, 1938). In 1968, the building codes were amended and the minimum required live roof load for flat roofs was reduced to 30 psf (Department of Buildings, 1968). Buildings were selected that were constructed prior to 1968 assuming such buildings would have a greater live roof load.

The following image is a schematic rendering of the Arc GIS model builder for Phase 1 and a map of the results.



Map 2: NYC Buildings with Green Roof Potential



VII. Preliminary Findings & Area of Interest Refinement

The preliminary GIS analysis as described in the Methodology- Phase 1 section for the 2009 buildings shapefile of the five boroughs of New York City, resulted in 5,701 buildings having the potential for rooftop agriculture. For the purpose of this study, given the time frame and resources available, the area of interest needed to be drastically reduced in scale in order to perform a more comprehensive analysis of the potential for rooftop green infrastructure.

The Newtown Creek Alliance is a non-profit organization that has expressed a great deal of interest in promoting and implementing green infrastructure including urban agricultural projects in the Newtown Creek watershed. Newtown Creek is an industrial area that straddles the boroughs of Brooklyn and Queens and was declared a U.S. Environmental Protection Agency Superfund site in 2010 (Urban Design Lab, 2011). The following map is the same as Map 2 with an inset highlighting the Newtown Creek watershed. The efforts of the Newtown Creek Alliance parallel the goals of NYC's Green Infrastructure Plan, which includes utilizing green infrastructure to mitigate the area's urban heat island effect, reducing air pollution and storm-water runoff caused by impermeable surfaces in the area. (New York City Dept. of Environmental Protection, 2010).

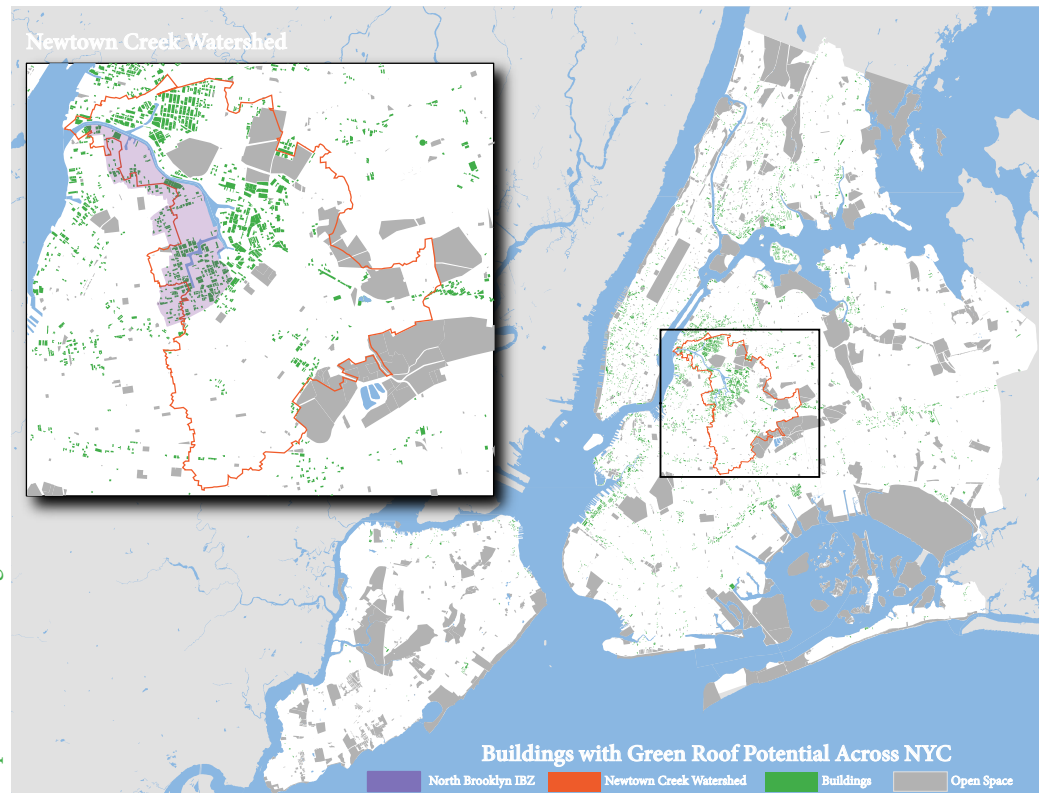
The North Brooklyn Industrial Business Zone (IBZ) is an area of concentrated green infrastructure interest within the Newtown Creek watershed. IBZs were created by the New York City Economic Development Corporation (NYCEDC) in 2006 and have allowed for the expansion of business services to manufacturing and industrial businesses. IBZs also ensure areas will not be rezoned for residential uses (NYCEDC, 2013). The North Brooklyn IBZ is also

home one of the successful rooftop farms already operating in the city, Gotham Greens. Eagle Street Farms lies just outside the IBZ as does Brooklyn Grange Farms. The North Brooklyn IBZ has been chosen as the refined area of interest for this study in the hopes that the findings will be used by the Newtown Creek Alliance in their green infrastructure implementation efforts.

Image 6: Newtown Creek looking west



Map 3: NYC Buildings with Green Roof Potential



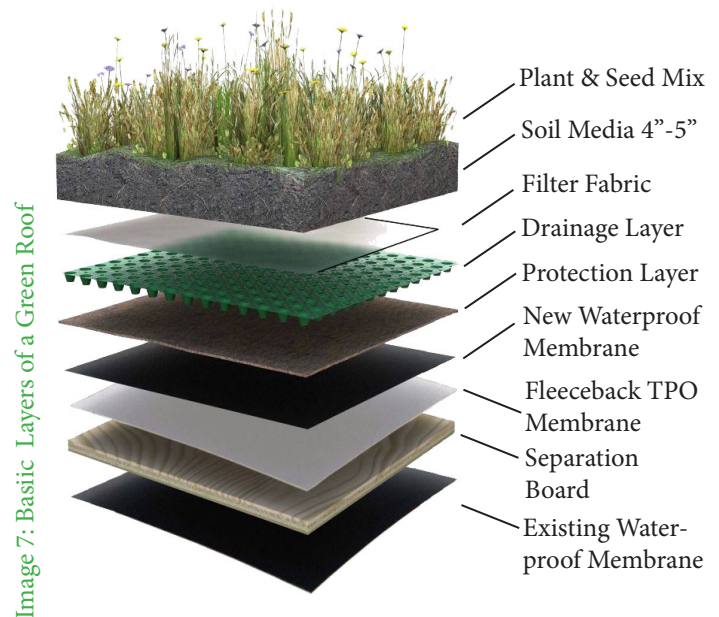
VIII. Methodology- Phase 2

With the revised area of interest the model was also revised. Instead of looking at the building stock through a binary lens, suitable for urban agriculture or not suitable, the revised model took a more flexible approach and resulted in a building ranking system based on suitability for rooftop urban agriculture; '1' is the least suitable and '6' is the most suitable. Buildings that were identified as having no potential for rooftop agriculture or green roof infrastructure did not receive a suitability ranking. Such buildings includes those with sloped roofs, less than 50% of the building footprint in usable roof area¹, and roofs that already had significant roof infrastructure². Phase 2 also modified the building selection criteria. Buildings were first selected that fell within the North Brooklyn IBZ. The North Brooklyn IBZ boundary shapefile was provided by the NYCEDC. Phase 2 of the model included the first three criteria from Phase 1: the building must be zoned for commercial or manufacturing use, have 10 floors or less and not be of noxious or city utility use. These are seen as non-negotiable site selection criteria for rooftop urban agriculture in New York City. The locations of noxious and utility use buildings were mapped separately in the Results section.

Upon further research, it was realized that the square footage of a roof is not necessarily indicative of its suitability for green roofing. However, it does dictate the scale of the project. Under 5,000 square feet is classified as a small scale operation, 5,000 – 40,000 square feet is a medium scale farm or greenhouse and a roof that is over 40,000 square feet has the potential to be a large scale farm, including rooftop greenhouses (Bay Localize, 2008). As a result, the square footage requirement in the model was modified. A new field was added to the building shapefile dataset, which classified the buildings' potential for small, medium or large-scale projects based on the building footprint area. No buildings were removed from the dataset based on square footage.

Additional research was conducted on the structural capacity needed for intensive and extensive

green roofs. Extensive roofs are typically less than 6 inches deep and have a maximum saturated weight of 10-35 psf. Intensive roofs have a deeper substrate to support a variety of larger vegetation and need a live load capacity of at least 35 psf. The basic layers of green roofs, both intensive and extensive are shown below. Depth and weight vary with project intensity.



After getting a better idea of the roof live load capacity needed to support various types of green roofs, the model was amended to classify a building's potential for an extensive or intensive green roof (including greenhouse) based on the year of construction. As discussed in Phase 1, buildings constructed prior to 1968 were required to have a greater live roof load than those built after 1968, the year the building codes changed. Therefore, buildings constructed prior to 1968 were classified as having the potential for an intensive green roof including greenhouses and those constructed after 1968 were classified as having the potential for an extensive green roof. This classification system is generalized. A structural engineer should evaluate the structural capacity of a building's roof before any green roof infrastructure is installed. Given the time and scope of this project, generalizations had

¹ Usable roof area was calculated using the NYC Solar Map. Details are provided on page 22.

² Roof infrastructure includes but is not limited to photovoltaic installations, large air conditioning units and existing greenhouses.

to be made for the model to be completed. Buildings constructed after 1968 may very well have live roof loads greater than the required minimum of 30 psf.

The table below shows building and operation information for select commercial rooftop farms in New York City.

Table 1: NYC Roof Farms

Name	Location	Year Built	Size (ft²)
Brooklyn Grange	Long Island City	1919	40,000
Brooklyn Grange	Brooklyn Navy Yard	1958	45,000
Bright Farms (greenhouse)	Sunset Park	1916	100,000 (planned)
Eagle Street Farms	Brooklyn	1931	6,000
Eli Zabar's (greenhouse)	Manhattan	1930	20,000
Gotham Greens	Brooklyn	1963	15,000

The building's (not operation) year of construction of these 6 farms bolsters the assumption that buildings built prior to 1968 are the most structurally suitable to support a commercial roof farm. These findings supported the design of the suitability matrix, which was created to calculate a building's s

There are 1,816 buildings within the North Brooklyn IBZ. The buildings were ranked from 1-6 (1 being the least suitable) on their suitability for rooftop urban agricultural projects. For the purpose of this report, large buildings with higher live roof loads (built prior to 1968) were considered the most suitable due to their potential to support large-scale urban agriculture projects through intensive green roofs or greenhouses. Smaller buildings with lower live roof loads were considered as having the least suitability for commercial urban agricultural projects but may still suitable for extensive green roof installations depending on the slope of the roof. The following image is the rooftop

Table 2: Suitability Matrix

Rooftop Agriculture Suitability Matrix	Intensive Built prior to 1968	Extensive Built after 1968
Small Scale Area <= 5,000 sq.ft.	2	1
Medium Scale Area 5,000 - 40,000 sq.ft.	5	3
Large Scale Area >= 40,000 sq.ft.	6	4

This suitability ranking system is purely based on the data provided in the building shapefile. Actual roof conditions needed to be examined outside of the GIS model. Roof

conditions were examined using Bing maps to verify the roof was visibly flat and largely free of protrusions or obstructions. The buildings with non-flat roofs were removed from the dataset as the types of green roof infrastructure discussed in this study are not applicable on sloped roofs. NYC Solar Map website was also

used in verifying the amount of usable roof space for urban agriculture. The NYC Solar Map utilizes LiDAR (light detection and ranging) data of the city, which is not obtainable by the public in its raw form, to create an algorithm that calculates usable roof area for solar panel installations. The following is from the 'How It Works' section of the NYC Solar Map website:

“ The NYC Solar Map estimates rooftop solar potential using a computer model that calculates the incoming direct and diffuse solar radiation for every square meter of the City of New York. The model is based on the position of the sun, overall atmospheric conditions, latitude, and most importantly, shading. Shading is generated from a digital surface model derived from lidar data (light detection and ranging), which captures the surface elevation of the ground, buildings and trees.

The web application was built using OpenLayers, PostGIS, and jQuery. The map display uses the ESRI World Topographic Map and Bing aerial imagery, along with building and tax lot data from the New York City Department of Information Technology and Telecommunications, and address locator (geocoding) services from Google.

Usable roof area within each rooftop is estimated based on slope, roughness, available sunlight, and building shape. When the system estimates the solar potential of an arbitrary polygon, the total area within the polygon is treated as usable. The effects of azimuth and tilt angle are estimated using the PVWatts solar model from the National

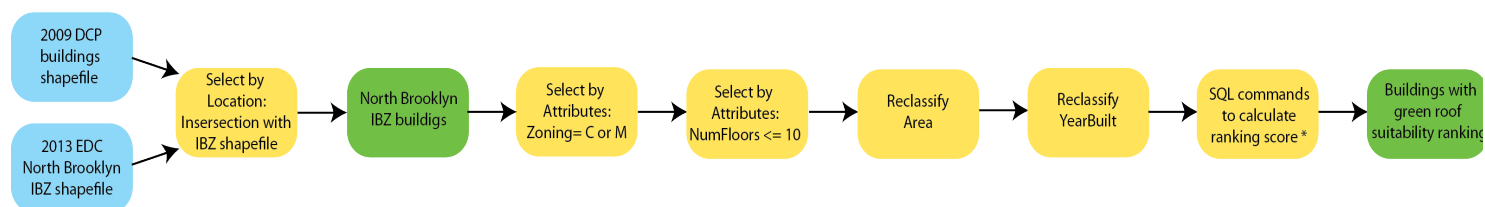
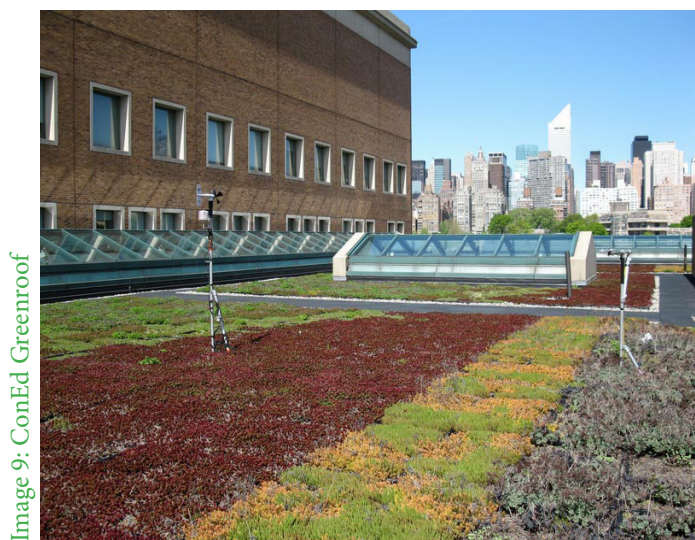
Renewable Energy Laboratory (NREL).

The solar model is published by ESRI, Inc. and was run on a high-performance computer generously made available by the CUNY High Performance Computing Facility. Model output was calibrated using available ground measurements including Typical Meteorological Year data from NREL, and validated using data from the Hunter College weather station and other available ground measurements.”
(nycsolarmap.com)

This urban agriculture study is assuming that roof area suitable for solar panel installations is also suitable for urban agriculture. Image 4 is of the mixed-use MetroVerde green roof in Jacksonville, FL, which integrates photovoltaics and vegetation on the same roof. If a building was identified as having less than 50% of its roof area suitable for solar panel installations (and therefore green roof infrastructure), it was removed from the dataset.

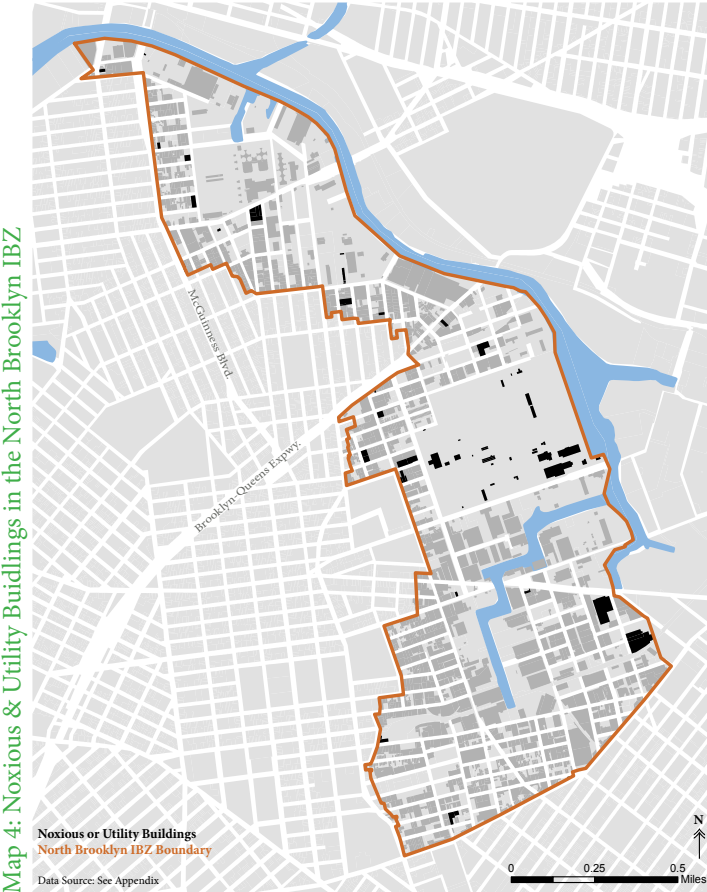
Building ownership has also been identified as an important aspect in the feasibility of urban agriculture and other green roof infrastructure projects. In some instances, it is easier to install a green roof on publicly owned buildings. For example, Chicago City Hall has mandated that any new building which utilizes public funds must be LEED-certified which often includes a green roof. Additionally, any project that includes a green roof design is expedited in the permitting processes (Melker, 2012). City governments can easily mandate green roofs on public buildings but have no such power over private buildings. The Newtown Creek Alliance has targeted publicly owned buildings for their green roof initiatives (Newtown Creek Alliance). For-profit businesses such as commercial roof farms usually need to take place on private roofs. However, the Alterrus greenhouse in Vancouver is a rent-paying tenant to the city for the use of their park

ing garage roof. Additionally, the NYCEDC issued a request for proposals in June 2012 for a roof farm on a publicly owned building in Hunts Points, Bronx (Foderaro, 2012). In light of this, building ownership was not integrating into the ranking matrix but rather included as an informational layer on the maps. The revised GIS schematic model is found below.



IX. Results

There is approximately 329 acres of roof space in the North Brooklyn IBZ, which is just under half of the area of Central Park. Buildings with a noxious or utility use account for 5% of the total building stock in the IBZ and although they likely cannot support rooftop urban agriculture projects, such buildings do have the potential for non-agricultural green roofs if they have flat roofs. The locations of noxious and utility use buildings are shown in the following map. These buildings were removed from the model and displayed separately. The majority of the buildings shown below are owned by the Brooklyn Gas Company.

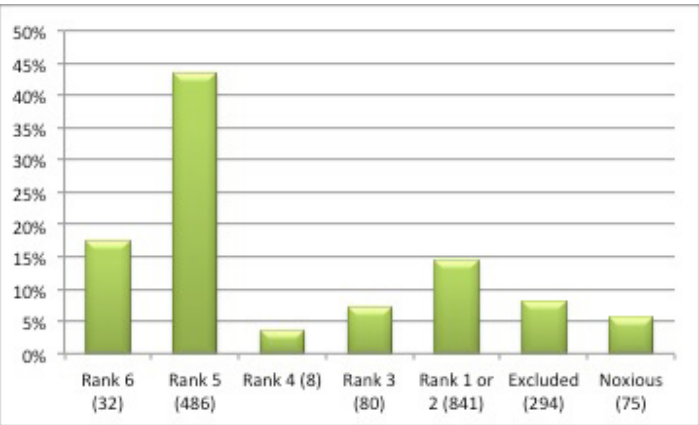


The model resulted in every building that met the basic requirements for zoning and number of floors in the North Brooklyn IBZ receiving a score from 1 to 6 on its suitability for a commercial roof farm. Buildings that received a 6 were evaluated as having the greatest potential for a commercial roof farm, greenhouses or an intensive green roof and buildings that received a 1 were identified as have the least potential for such infrastructure. Buildings that received a 0

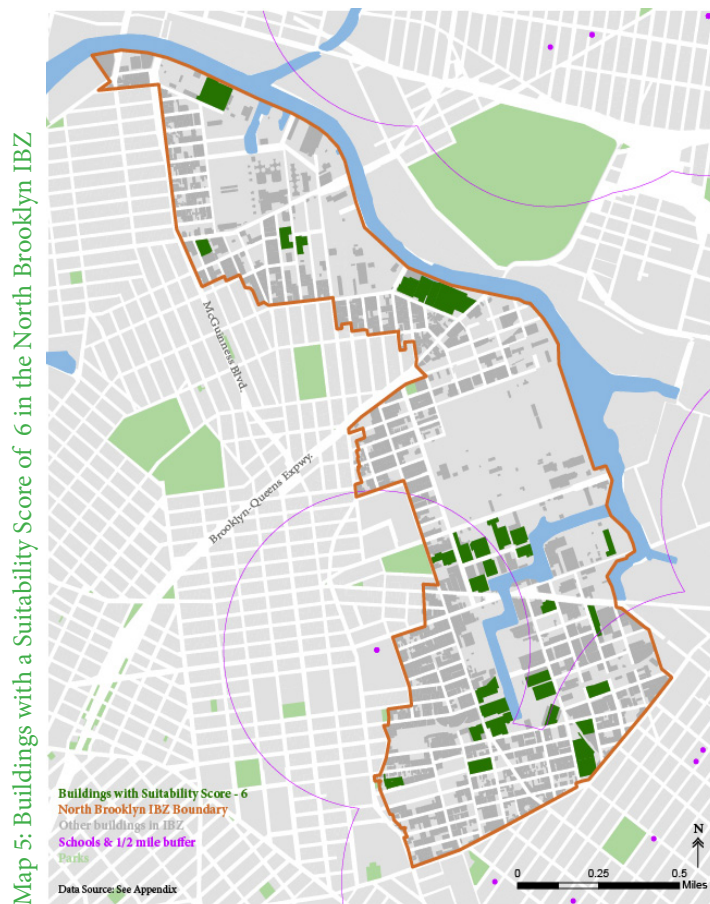
were excluded and include structures with sloped roofs, residential uses, large roof obstructions or roofs that had less than 50% of the footprint area in usable space. The following describes each suitability score:

- 6- high potential for commercial roof farm, or intensive green roof
- 5- medium potential for commercial farm, green house or intensive green roof
- 4- high potential for non-agricultural green roof
- 3- medium potential non-agricultural green roof
- 1 & 2- No potential for commercial farm, greenhouse or intensive green roof. Low potential for non-agricultural green roof.

The following chart visualizes the distribution of green roof suitability as a percentage of the total building stock within the IBZ and number of buildings that correspond with each classification.

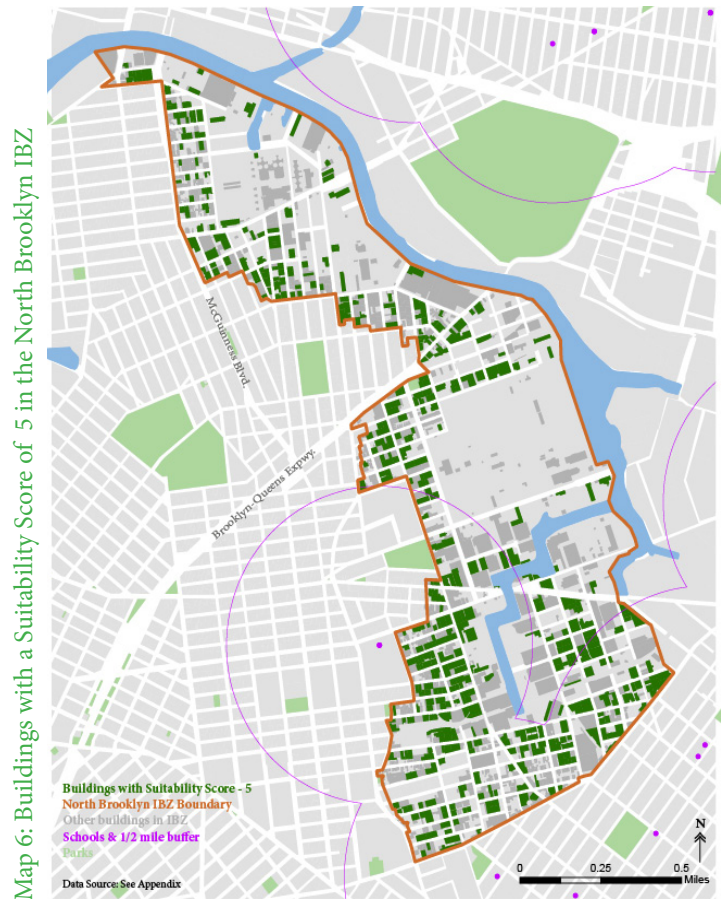


Buildings that received a suitability score of 6 have been identified as having the greatest potential for roof top urban agriculture due to the area of the roof, construction year, use and zoning designation. Buildings that fall within the ½ mile buffer from schools within the Newtown Creek watershed are the most desirable for roof top urban agriculture projects as they are in close proximity to an institutional end user (schools) and have the potential to serve as educational farms (Urban Design Lab, 2011) (Newtown Creek Alliance). These buildings account for roughly 17% (55.8 acres) of the total roof area in the IBZ. Over half of the roof area of these buildings are within ½ mile of a school. The following map shows the location of these buildings.



Buildings that received a suitability score of 5 are considered as having a lower potential for rooftop urban agriculture than those buildings that received a 6 due to their smaller roof area of 5,000 to 40,000 square feet. Roofs of this size are likely to be structurally capable of supporting rooftop urban agriculture, greenhouses or intensive green roofs as they were constructed prior to 1968. The majority of buildings within

the IBZ scored a 5. These buildings account for 43% of the total roof area in the IBZ or 139.62 acres. Buildings with a suitability score of 5 that are within ½ mile from a school account for 22% of the total roof area in the IBZ or 73.7 acres. The following map shows the location of buildings that have a suitability score of 5.



Buildings that scores a 4 for suitability for roof top urban agriculture are in the same size category as buildings that scored a 6, over 40,000 square feet, but due to their construction post-1968 it is assumed that their live roof load is not conducive to a rooftop farm, greenhouse or intensive green roof. However, these buildings have a high potential for an extensive green roof project. The environmental benefits of large green roofs in the Newtown Creek watershed include urban heat island mitigation and decrease in storm water runoff and pollution. So while these buildings are not likely suitable for urban agriculture they are extremely suitable for large green infrastructure projects. Buildings that fell in this category made up with smallest of total roof area of the IBZ at 11.96 acres or 4%. The locations of buildings with a suitability score of 4 are shown on the following map.

Map 7: Buildings with a Suitability Score of 4 in the North Brooklyn IBZ



Map 8: Buildings with a Suitability Score of 3 in the North Brooklyn IBZ



Buildings with a suitability score of 3 likely do not have the live load capacity to support intensive green roofs but due to their medium size, 5,000 – 40,000 sq. ft., they are suitable for moderately sized extensive green roofs. Similar to those buildings, which had a suitability score of 4, these roofs likely do not have agricultural potential but can be utilized for other green roof infrastructure. Buildings with a suitability score of 3 account for a total of 23.59 acres or 7% of the total building roof area in the IBZ. Map 8 shows the locations of these buildings. The remaining buildings received suitability scores of 1 or 2. These roofs are not viable for commercial agriculture due to their size and/or live roof load capacity. These buildings could accommodate small-scale extensive green roofs but due to their small area they would have minimal environmental benefits. Secondary analysis using aerial imagery and the NYC Solar map was not performed on these buildings. The following map shows the buildings, which received suitability scores of 1 or 2 for their potential to support urban agriculture. Buildings under 5,000 sq. ft. typically have sloped roofs which would make them largely unsuitable for green roof infrastructure. Map 9 shows the location of these buildings.

Map 9: Buildings with a Suitability Score of 1 or 2 in the North Brooklyn IBZ



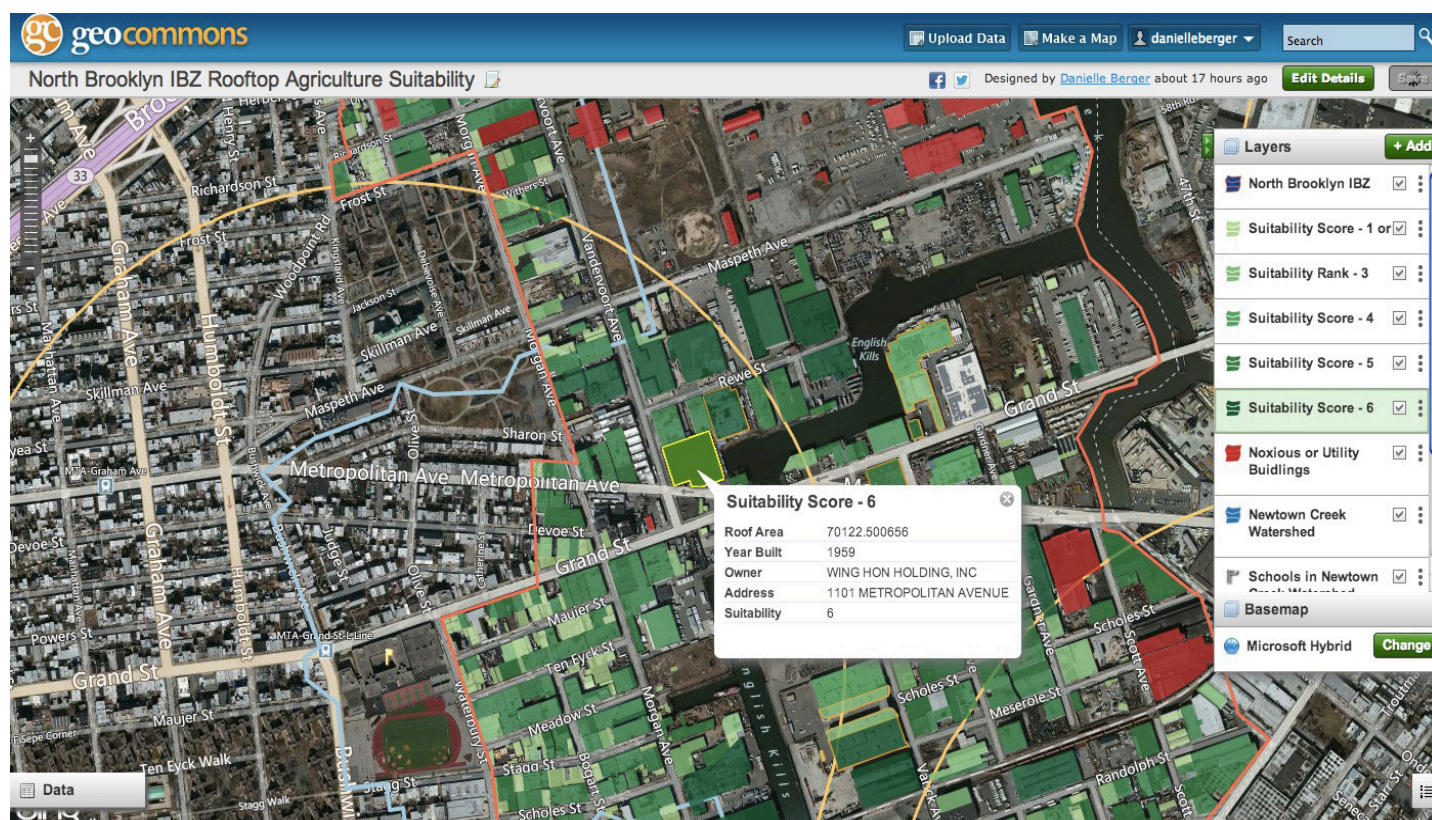
The model did not recognize adjacent rooftops. In a few instances, as observed using Bing maps, there are adjacent roofs with continuous surfaces, where there are no roof top obstructions between buildings. In these circumstances, the actual continuous roof space is greater than the roof area calculations derived from the building footprints. These roofs present interesting opportunities for roof top agriculture through building owner partnerships. It should also be noted that there was a significant amount of secondary analysis performed on the buildings that had a suitability score of 3 or greater using GoogleEarth Pro, BingMaps and the NYC Solar Map to verify roof conditions. The GIS model does a very good job at a first level analysis of rooftop suitability for urban agriculture but human verification was needed to ensure accuracy.

Interactive Web Map

In today's digital culture where nearly everything has an online presence, it was imperative for the results of this model to be available online with interactive features. An interactive web map with the results from this model are available online at <http://www.geocommons.com/241923>

The results of this geospatial model have the potential to be leveraged by urban planners, urban farmers, businesses, academics, advocacy groups and the general public to increase awareness and spur the implementation of green roof technology in the North Brooklyn Industrial Business Zone. The data layers on the interactive web map were derived from ArcGIS 10.0 and the publicly available datasets used in the model. The web map utilizes pop-up information boxes so the user can find the owner, roof area, suitability score and address of the building of interest. The online presence of the model results allows the data derived from this study to reach as large an audience as possible. The data is not downloadable so it does not violate any distribution restrictions. The following image is a screenshot from the webpage.

Image 10: Screenshot of GeoCommons Webpage displaying model results



The Dark Greens Potential

To try and quantify and imagine the yield potential of the most agriculturally suitable buildings the following scenario uses dark greens³ as an example crop. The 32 buildings identified as having the greatest potential for urban agriculture (a suitability score of 6) have a total roof area of 55 acres. The demand for dark greens in New York City has been calculated at 155,616,899 lbs/year (Urban Design Lab, 2011). The average yield for dark greens is 0.49 lbs/psf using conventional farming methods (Urban Design Lab, 2011). Therefore, if all 32 buildings were growing dark greens using conventional methods, they could produce nearly 1.2 million pounds of produce per year. Although it may seem that roof-grown dark greens would only put a small dent in the NYC consumption figure, if taken to scale across the city or the metropolitan region, there is potential to contribute significantly to the local market. Dark greens are considered one of

the most profitable urban crops as they are easy to sell either directly to restaurants or local markets due to high consumption demand. Fresh dark greens also lose nutrients more quickly than other crops. This means reducing travel distance from farm to table is a high priority. Greenhouse yields are significantly greater than conventional farming but difficult to quantify in terms of pounds per square foot. Gotham Greens is an existing successful rooftop greenhouse in the North Brooklyn IBZ that exclusively grows dark leafy greens. Their greenhouse is currently growing red sails lettuce, basil, baby butterhead lettuce and tropicana green leaf lettuce and supplies various retailers, farmer's markets and restaurants with their produce. Gotham Greens, along with the other roof farms in NYC, show that urban agriculture can be a profitable endeavor with positive impacts on the environment, public health, local food supply and small businesses.

Image 11: Inside Gotham Greens' Green-



³ Dark greens include broccoli, collard greens, escarole, kale, lettuce (leaf), mustard greens, spinach and turnip greens.

A Closer Look at The Most Desirable Buildings

Of the 32 buildings which had a suitability score of 6, 16 of those buildings are within 1/2 mile of a school. These buildings are considered to have the greatest potential for rooftop urban agriculture in the North Brooklyn IBZ due to their structural and political characteristics. Although there are buildings that lie just outside the 1/2 mile buffer which also received a suitability score of 6, for the purpose of this report satellite imagery will only be provided for the buildings within the buffer. The models appear to have done an excellent job in identifying the most ideal buildings for rooftop agriculture in the North Brooklyn IBZ as evident through the satellite images below. Building information was derived from Oasis NYC and the 2009 PLUTO dataset. Three building clusters were identified, Properties 1- 4, Properties 5-9, and Properties 10-12. The remaining 4 properties were not part of a defined cluster. These clusters have a significant amount of roof area capable of supporting urban agriculture in close proximity to one another. The clustering of roof farms (excluding greenhouses) and extensive green roofs is assumed to have greater environmental benefits than non-clustered green roofs (Federal Energy Management Program, 2004). Green roofs have the ability to cool the ambient temperature by 16.4°C per unit area, therefore clustered green roofs have a greater potential to mitigate the urban heat island effect (Moisse, 2010). Additionally, clustered outdoor roof farms are expected to be better for plant pollination, particularly in industrial areas.

Property 1



Property 3



Property 2



Property 4



Property 5



Property 8



Property 6



Property 9



Property 7



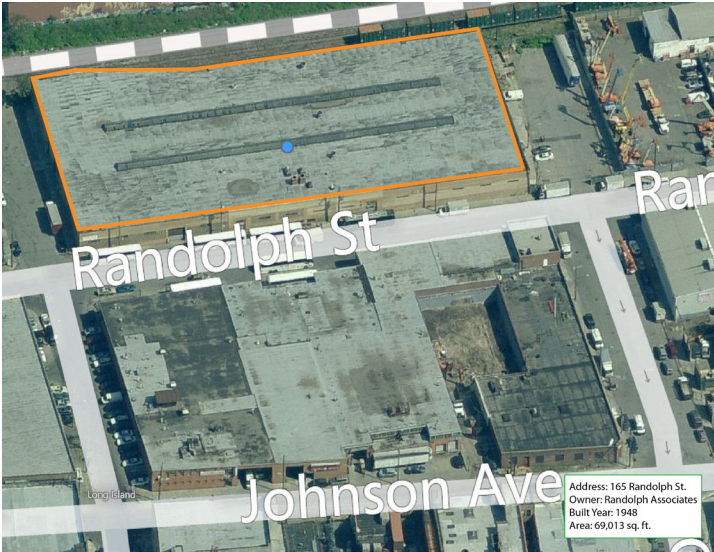
Property 10



Property 11



Property 14



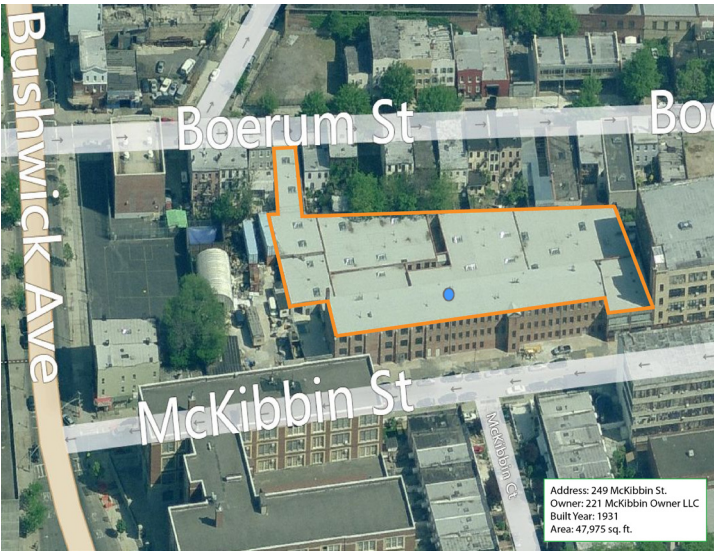
Property 12



Property 15



Property 13



Property 16



X. Policy Recommendations

For sustainability planning and policy-making there are a few different approaches and techniques, which can be pursued based upon the results of this GIS analysis. The first is to increase awareness about the structural potential for green roof infrastructure. The results of this model would be directly used for this initiative. If building owners are made aware of their building's potential for urban agriculture it could start a dialog between landlords and potential farm tenants. It's also important to off-set the cost of green roof installations through tax credits and rebates. Green roof installations start between \$10 - \$25 per square foot depending on the intensity of the roof and cost between \$0.75- \$1.50 per square foot in annual maintenance (Peck, 2003). Undoubtedly, green roofs are more expensive to install and maintain than traditional asphalt roofs, yet traditional roofs do not provide any environmental or social benefits. So are conventional asphalt roofs really less expensive? There needs to be adequate financial incentive programs to convince building owners to install green roof infrastructure.

On April 30, 2012, the city enacted the Zone Green amendments, which excludes rooftop greenhouses from a building's FAR as long as it meets certain height and use requirements (NYC, Dept. of City Planning, 2012). This was a progressive first step towards integrating agriculture into the urban landscape of New York City. There are currently various rebate programs at the federal, state and local level for green roof owners. The NYC Green Roof Property Tax Abatement Program allows for a 1-year tax abatement for \$4.50 per square foot of green roof up to \$100,000⁴ (NYC Dept. of Buildings, 2010). The New York State Green Building Credit allows for rebates ranging between 5-8% of allowable building costs (Kneeland, 2000). There are also various EPA tax credits available. There needs to be increased awareness of these rebate programs and how green roofs can be financially achieved. Due to high cost of green roof installation, a suggestion could be to offer a rebate up to a certain percent of the total installation cost as opposed to a fixed dollar amount per square foot. Additionally, there could be a property tax credit for those buildings with green roof infrastructure.

The other way of approaching this issue is to charge building owners a stormwater runoff tax. This form of taxation is currently being implemented in several municipalities across the country and charges building owners by the amount of stormwater which runs off their property. This is calculated by the area of impervious surface of a building. Therefore, the larger the impervious roof, the greater the tax.

Based on the methodology Phase 1 results in this model, there are over 3,000 acres of roof space that could potentially be used for urban agriculture. This is based on the more generalized selection criteria of Phase 1 and is not as accurate as Phase 2. However, for the purpose of trying to imagine the potential for rooftop agriculture and green roofing across the city, these figures will suffice. It would cost in the ballpark of \$1.3- \$3.2 billion to install green roofs on every roof larger than 10,000 ft² across the city. This figure should be seen as catalyst to improve and continue government rebate programs to offset these costs to promote sustainability in urban areas and contribute to the local food supply. In addition, it calls for further study as to exact costs and needs for land use changes and perhaps public subsidies or investments. There is a larger social good not captured by the value of the produce alone that urban society should be promoting this programatically with policy changes and public investments.

Newly constructed city-owned buildings should also be required to implement some form of greenroof infrastructure on roofs which permit it. This is being practiced in Chicago, IL and has been successful in increasing public awareness of the environmental benefits of green roofs. Additionally, current city-owned buildings should be required to analyze the potential for greenroof infrastructure and retrofit existing roofs where possible. By promoting the implementation of green roofing at the city level, there is likely to be greater interest among the general public and private building owners.

⁴ This abatement program ended March 15, 2013.

XI. Conclusion

Urban agriculture has the potential to provide New York City with diverse and substantial benefits ranging from reduction in storm-water pollution to public health and job creations. The results of this GIS model are on the bleeding edge of geospatial analysis for urban agricultural and have an incredible power to be leveraged by planners, developers, urban farmers, advocacy groups and the public. The results of this GIS model indicate there is a substantial amount of roof area that has the structural potential to support rooftop agriculture, and to a greater extent green roof infrastructure, in the North Brooklyn Industrial Business Zone. This model looks at the structural feasibility for rooftop agriculture and does not incorporate the economics of rooftop farming. Because of this, the results of the model show which buildings have the greatest structural potential for rooftop farms. The success of a farm is largely the result of farming practices and business operations. Other constraints need to be taken into consideration before a rooftop farm can be built such as ingress/egress routes, parapet heights and prevailing winds. Larger roofs have the potential to support larger farms, which can be assumed as having a greater potential for economic viability but that is not to discount the economic potential medium size (5,000 -40,000 sq. ft.) roof farms. Hopefully the results of this model will be utilized by the Newtown Creek Alliance in their green infrastructure initiatives, whether it is encouraging roof farms to located in with the North Brooklyn IBZ or simply encouraging building owners to install an extensive green roof on their building. Lufa Farms is the largest rooftop greenhouse in Montreal, QC, Canada and they are actively looking for roof space to expand their operations south of the border. Additionally, growing urban farm business like Brooklyn Grange and Bright Farms are in the process of expanding within New York City.

Urban agriculture needs to be integrated into planning, development projects and policy-making in New York City to increase the sustainability of the city by reducing the negative effects of urban landscapes and contributing to the local food supply. Green roofs with food producing capabilities and greenhouses have contrasting benefits and drawbacks although they are both components of rooftop urban agriculture. Greenhouses have significantly higher crops yields than conventional outdoor farms and the ability to grow produce year round due to climate controlled environments. However, greenhouses do not reduce storm water run-off, mitigate the urban heat island effect or have reduce air pollution. On the other hand, food-producing green roofs have environmental benefits which greenhouses do not, but have significantly lower annual crop yields.

The results of this GIS model have not been presented before in a cohesive, accessible manner before to the public, buildings owners and planners. The model has the potential to change the way rooftop urban agriculture is quantified and identified in urban landscapes. The North Brooklyn IBZ was used as a case study neighborhood for how this GIS model can be implemented largely because of the interests of the Newtown Creek Alliance in expanding their green infrastructure initiatives. The processes of the model can be replicated in any part of the New York City and in any city in the world, given the proper datasets and metadata documents to evaluate the potential for urban agriculture. New York City is in an exciting position to become a world leader in urban agriculture and pioneer in rooftop agricultural practices.

XII. Appendix

Data Sources

Data layer/Name	Source	Year
Newtown Creek watershed boundary	Newtown Creek Alliance	2013
North Brooklyn Industrial Business Zone	NYC Economic Development Corp.	2013
Building footprints	NYC Dept. of City Planning, PLUTO	2009
Schools	NYC Dept. of City Planning	2012
Aerial imagery	Bing Maps	2013
Additional building information	OASIS NYC	2013
Usable roof area	NYC Solar Map	2012

Photo Credits

Image 1: VertiCorp greenhouse- <http://yulupr.com/webdev/wp-content/uploads/2012/01/verticrop.jpg>

Image 2: NYC Green Carts- <http://www.fairfoodnetwork.org/>

Image 3: UHI Effect- http://switchboard.nrdc.org/blogs/pbull/starting_at_the_roof_top_for_u.html

Image 4: UHI Effect temperatures- <http://www.southwesturbanhydrology.com/>

Image 5: Fisheye view of Manhattan- <http://mamacue.me/2012/08/27/messaging-nightmare-latch-on-nyc/>

Image 6: Newtown Creek view- <http://blogs.ei.columbia.edu/2010/09/30/>

Image 7: Green roof layers- <http://www.sustology.com/>

Image 8: MetroVerde roof- <http://metroverde.com/>

Image 9: ConEdison roof, Queens- http://www2.marketwire.com/mw/frame_mw?attachid=824684

Image 10: Interactive webmap screenshot- <http://www.geocommons.com/241923>

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